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Shift Schedules for Emissions and Fuel Economy Testing

by
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Shift Schedules for Emissions and Fuel Economy Testing

The aspect of shift schedules in emissions and fuel economy testing is an important one. The timing of the shifting of gears over the certification driving cycle has a significant effect on the emissions and fuel economy of the vehicles tested. The purpose of this report is to examine the current method of determining the shift schedules used during certification and determine if this method is resulting in shift schedules which are representative of those used by typical drivers. The history of the method of determining shift schedules for the certification process is first examined. Then the current trends of shift schedules found in vehicle owner's manuals are determined, since these are the sources of the shift schedules used during certification. Next, the methods of determining shift schedules of other automobile testing organizations are examined, as well as how people are taught to shift in driver's education schools. Finally, data are presented comparing on-the-road shift speeds to those recommended by the manufacturers.

A summary of the shift points recommended by the above sources is presented in Table #1. In Table #2, results from studies examining the actual shifting of vehicles on the road are compared to those shift speeds recommended by the manufacturers. In Tables #2b and #2c, the average shift speed is comparable to the higher limit of the manufacturer's recommended shift speed, while the cruise speed at which up-shifting occurred half the time is comparable to the lower limit.

Table #1

Comparison between Shift Points Recommended by Various Sources

Shifts	Historical Perspective*	Owner's Manuals Pre-1974**	74-76	76-78***	Training Manuals	Testing Organizations #
1-2	15	-	10-20	10-20	10-15	-
2-3	25	-	20-30	15-30	15-25	-
3-4	40	-	30-40	20-50	35	-

* Previously required shift schedule included in Federal test procedures.

** Previous to 1974, few owner's manuals recommended specific shift points.

*** Many owner's manuals since 1976 include additional stipulations like shift into the highest possible gear once cruise speed has been reached and listing the range of cruise speeds for each gear. This can mean recommending double upshifting. One manufacturer is also recommending different shift points for a cold and a hot engine.

\# Other testing organizations recommend that their drivers shift when it seems reasonable.

Table #2

Comparison of Average Actual Shift Speeds with Those Recommended by Manufacturers

Table #2a: 1-2 Shift

Vehicles (1977 unless noted) (Tester)	Monza (GM)	Chevette (GM)	Nova (GM)	Camaro (L-6) (GM)	Camaro (V-8) (GM)	C-10 Pickup (GM)	1976 Rabbit (GM)	1976 Pinto (Ford)	VW Rabbit (EPA)	Corolla (EPA)	Chevette (EPA)	Pacer (AMC)	Gremlin (AMC)
Actual % Rated RPM	70	69	64	71	61	63	65	79	63	57	64	67	63
Actual* Shift Speed-MPH	19.3	15.9	21.5	23.8	19.8	22.0	18.1	23.3	17.3	15.7	16	18.7	18.8
Manufacturer's Recommended Shift Speed-MPH	10	10	20	20	15	15	15	10	15	12	10	10-15	10-15

	Actual Percent Rated RPM	Actual Shift Speed - MPH	Manufacturer's Recommended Shift Speed - MPH
Thirteen Vehicle Average	66	19.2	4.0
Standard Deviation	5	2.7	3.5

*GM's analysis of the road data for the 1-2 shift used only those shifts which resulted in continued acceleration.

Table #2b: 2-3 Shift

Vehicles (1977; GM)	Monza	Chevette	Nova	Camaro (L-6)	Camaro (V-8)	C-10 Pickup	1976 Rabbit
Average shift speed from on the road testing-mph (% of rated RPM)*	28.4 (73)	27.2 (68)	34.6 (61)	36.9 (65)	28.4 (62)	36.2 (61)	30.9 (63)
Cruise Speed at which the vehicle was shifted half the time - mph (% of rated RPM)	23 (59)	19 (48)	27 (48)	26 (46)	19 (42)	30 (51)	24 (49)
Manufacturer's Recommended Shift Speed	15-30	25	25-40	25-40	25	25-40	19-25

	Average Speed	50% Cruise Speed	Manufacturer's Recommended Shift Speed Upper Limit	Lower Limit
Seven Vehicle Average - MPH (% Rated RPM)	31.8 (65)	23** (49)	32.1	--
Standard Deviation MPH (% Rated RPM)	4.0 (4)	3 (6)	7.6	--
Four Vehicle*** Average - MPH	--	25	--	21.0

* GM's analysis of road data for the 2-3 shifts of 4 speed vehicles included only those shifts which resulted in continued acceleration. Shifts into cruise made were included in the analysis of the 3 speed vehicles. Thus, these values for the 3 speed vehicles are expected to be lower than the upper limit of the manufacturers recommended shift speed.

** C-10 pickup 50% cruise speed has been excluded because insufficient data was available for reanalysis.

*** 4 vehicle average is shown to allow comparison between cruise speed and lower limit of manufacturers recommended shift speeds; excludes Chevette, C-10 pickup, and V-8 Camaro.

Table #2c: 3-4 Shift

Vehicles (1977; GM)	Monza	Chevette	Camaro V-8	1976 Rabbit	Four Vehicle Average	Standard Deviation
Average shift speed from on the road testing-mph (% of Rated RPM)*	36.8 (63)	37.0 (59)	33.6 (49)	40.8 (58)	37.1 (57)	2.9 (6)
Cruise Speed at which the vehicle was shifted half time time-mph (% of rated RPM)	31 (53)	32 (51)	31 (45)	32 (46)	31.5 (49)	0.6 (4)
Manufacturer's Recommended Shift Speed	20-50	25-40	25-40	25-40	42.5 (Upper Limit) 23.8 (Lower Limit)	

* GM's analysis of road data for the 3-4 shift included shifts into cruises. Thus, these values are expected to be lower than the upper limit of the manufacturers recommended shift speed.

The primary conclusions of the report are:

1. There is no inherent reason to believe that the shift schedules recommended by the manufacturers in their owner's manuals are representative of the way people drive on the road;

2. Many of the shift schedules being currently used during certification are not representative of typical driving and are resulting in higher fuel economy and lower carbon monoxide emissions on cars tested over the urban driving cycle. In particular, drivers on the road:

   a) Shift into second gear at a significantly higher vehicle speed than is recommended by the owner's manuals;

   b) Shift into cruises only at higher speeds than recommended by the manufacturers;

   c) Do not shift from an acceleration into a deceleration in the same way they shift from an acceleration into a cruise. Thus, a distinction between these two occurrences should be made during certification testing; and

   d) Do not double up-shift vehicles with 3 and 4 speed transmissions.

3. From the data available, it appears that using the manufacturer's recommended shift schedules as compared to representative in-use shift patterns results in a 10-15% increase in urban fuel economy and a 4-30% decrease in carbon monoxide emissions. The effect of shift schedules on hydrocarbon and nitrogen exoide emissions appears to be more vehicle specific.

4. Of the three consumer oriented automotive testing groups surveyed, none used the shift schedules listed in the owner's manuals to determine when they shifted their test vehicles;

5. If the shift schedules used during certification are to be made representative, a change will be necessary in the current method of determining shift schedules.

Four possible alternative methods of determining certification shift schedules are presented:

a) Develop a detailed correlation which would determine the shift schedule from vehicle specific parameters (i.e., power to weight ratio, N/V, etc.); allow variations only if the manufacturers could demonstrate that the variations were more representative. (This would most likely require a change in the regulations since EPA would be specifying the shift schedules for each test vehicle and would require a significant amount of time in order to collect the necessary data.)

b) Return to the old standard 15-25-40 mph shift schedule; allow variations only if the manufacturers could demonstrate that the variations were more representative.

c) Require all manufacturers to demonstrate that their currently recommended shift schedules are representative of how their vehicles are driven on the road, if challenged by the certification staff (using the guidelines of this report as a basis for challenges); and

d) Allow certification drivers to shift when they feel appropriate.

The recommendation of this report is that method c) be implemented as soon as possible. The following guidelines appear to be most useful to assure that vehicles are shifted in a manner representative of in-use operation:

1. The 1-2 shift point should be at 66% of rated engine RPM, possibly allowing up to a 5% of rated RPM deviation;

2. The 2-3 shift point should be at 65% of rated engine RPM, possibly allowing up to a 4% of rated RPM deviation;

3. The 3-4 shift point should be at 57% of rated engine RPM, possibly allowing up to a 6% of rated RPM deviations;

4. The minimum speed at which a vehicle is allowed to up-shift into a cruise should be at 49% of rated engine RPM, possibly allowing up to a 5% of rated RPM deviation;

5. A cruise in the Federal certification driving cycle should be defined as a period of time at least three seconds long during which all accelerations and decelerations (over one second intervals) are of an absolute magnitude of 0.5 mph per second or less;

6. The minimum speed at which a vehicle is allowed to up-shift into a deceleration from an acceleration (no cruise as defined in #5 occuring in between) should be the same speed as for up-shifting into an acceleration, which is stated in guidelines #1, #2, and #3;

7. No double shifting of vehicles with 3 or 4 speed transmissions should be allowed;

8. If a manufacturer's recommendation does not meet the previous guidelines, he should be allowed the opportunity to submit data supporting the deviations. If no convincing data are presented, the above guidelines should be used for shifting that vehicle during certification testing.

Historical Perspective of Federal Testing Procedures

The history of specifying shift points in driving cycles goes back to March 30, 1966 (8). At that time, the California 7-mode cycle had just become the Federal Test cycle. The shift points over this cycle were set uniformly for all cars. The shift points were 15 mph, for shifting from first to second gear, 25 mph, for shifting from second to third gear, and 40 mph for shifting from third to fourth gear, if there was a fourth gear.

This procedure remained until July 15, 1970 (9). At this time, the modified LA-4 cycle with a cold start (1972 FTP) became the Federal Test cycle. The development of this cycle involved operating a light-duty vehicle over the Los Angeles driving route 4 and collecting vehicle operational data. As the Driving Schedule developed from these studies, it became clear that vehicles could be operated on chassis dynamometers in a way that would reproduce the original trip characteristics. One aspect of real life vehicle operation which received attention during this development was the specification of shift points for manual transmission vehicles.

In the course of this development, several manual transmission vehicles (3, 4, and 5 speed) were driven over the schedule and the transmission shift characteristics were evaluated. The 15-25-40 mph shift points of the previous driving cycle were found to also be satisfactory for the new Driving Schedule. Since the Driving Schedule was developed to represent real life, and since real life drivers vary their gear shifting characteristics to suit the driving conditions, it seemed unnecessary to define rigid shift point specifications. It was expected that most vehicles would be shifted at about the 15-25-40 shift points in real life and that for vehicles which were likely to be shifted at other speeds, the manufacturers would provide guidance in the owners manual. With this in mind, the regulations were written to allow shifting at the manufacturer's recommended shift points or at 15-25-40 in the absence of such a recommendation. That the manufacturer's would recommend shift patterns that would not represent the way that most people would, in fact, shift those vehicles was not anticipated by the developers of the Driving Schedule.

On July 16, 1976 (11), the 15-25-40 mph shift points were deleted completely with the vehicles to be shifted according to the manufacturer's recommendation to the ultimate purchaser. No stipulation was made for the case where the manufacturer did not recommend shift points to the ultimate purchaser.

An important question to ask would be what happens if a vehicle is shifted too soon and cannot keep up with the driving trace? Currently (10, 11), Federal regulations restrict any deviations of the actual vehicle speed on the dynamometer from the speed shown on the driver's

aid chart. In Section 86.177-12 Manual Transmissions (11), it states that; "If the vehicle cannot accelerate at the specified rates, the vehicle shall be operated with the accelerator pedal fully depressed until the vehicle speed reaches the speed at which it should be at that time during the test." In Section 85.075-14 Dynamometer Driving Schedule (10), it states that; "Speed tolerances greater than 2 m.p.h. (such as occur when shifting manual transmission vehicles) are acceptable provided they occur for less than two seconds. Speeds lower than those prescribed may be acceptable provided that the vehicle is operated at maximum available power during such occurrances." While it might appear that Section 86.177-12 would allow lower than prescribed speeds in acceleration modes as long as the accelerator pedal was fully depressed, Section 85.075-14 would require that the vehicle be performing at maximum available power. These two requirements differ if the vehicle is being driven at low engine speed (i.e., relatively high gear for that vehicle speed), since the power can be increased by downshifting. Thus, a vehicle falling short of the prescribed speed would be required to downshift if downshifting would result in increased vehicle acceleration.

Current Trends in Manufacturer's Recommended Shift Points

The current test procedure for determining vehicle fuel economy and emissions, as laid out in the Federal Register, calls for the vehicle to be shifted as per the manufacturer's recommended shift schedule to the ultimate purchaser. As long as the shifting schedule in the owner's manual bears them out, the manufacturers are being allowed to shift their cars at any speed. The vehicles still must be able to follow the driving trace within the specified tolerances.

Since the recommended shift points found in the owner's manuals have such an important role in the way a certification vehicle is driven over the Federal Test Cycles, it is important to see how these recommendations have been changing over the years. Prior to 1974, the shift points for vehicles with manual transmissions were rarely specified. Thus, the standard 15, 25, and 40 mph shift points were used. For example, the 1971 Dodge Challenger manual gives general recommendations such as shifting through gears in their numerical order, and shifting from 2nd to 3rd as soon as practical in order to conserve fuel. Limits for downshifting are also given, to protect against over-revving the engine. Very rough up-shift points could be estimated from these downshift limits. For a three-speed transmission, the shift points would be 10 and 40 mph. For a four-speed transmission, they would be 15-25-50 mph. The 1968 Chevelle-Camaro-Chevy II manual also recommends shifting up a gear as soon as possible to increase fuel economy, but gives no vehicle speeds at which to shift. The 1970 Oldsmobile Cutlass manual does not even mention this, but does mention, along with Dodge and Chevrolet, to downshift to 2nd gear at low speeds to improve vehicle performance and acceleration. The 1973 Volkswagen manual did list recommended speed ranges for the various gears. From these ranges, it would be possible to determine the upper and lower limits for the various shift points. The upper limits would be 16, 34, and 56 mph. The lower limits would be 12, 22 and 31 mph, but would only be practical if all the desired acceleration had been completed. Since these limits actually only represent the two extremes of engine racing and lugging, the point of shifting is still left to the driver. The 1972 AMC owner's manual was the only one found to recommend specific shifting speeds. AMC recommends that the driver shift at 18 and 30 mph (three-speed transmissions), and 18, 25, and 40 mph (four-speed transmissions).

Beginning around 1974, most manufacturer's began to recommend specific speeds at which to shift their vehicles. Overall, while the rest of the section dealing with manual transmissions remained the same as prior to 1974, a short paragraph recommending specific shift speeds was now included. The 1974 AMC manual recommends shifting their three-speed manuals at 18 and 30 mph (15 and 25 mph with their 3.54:1 axle), and recommends shifting their four-speed manuals at 18, 25, and 40 mph. The 1975 Ford Pinto manual gives a range of shift speeds; 10-15 mph for a 1-2 shift, 20-30 mph for a 2-3 shift and over 30 mph for a 3-4 shift. The 1975 Chevrolet Nova manual recommends shifting at 20, 30, and 40 mph. The 1976 Plymouth (Grand Fury, Fury, Valient, Volare, Duster) manual

includes specific shift speeds for its Feather Duster model. These are 15, 25, and 35 mph. The Honda Civic manual recommends shifting at 15, 25, 40, and 45 mph.

The exact year that specific recommended shift speeds appeared, varied from manufacturer to manufacturer and even within a manufacturer's product line. Neither the 1976 Dodge (Monaco, Charger, Coronet, Aspen, Dart) manual, nor the 1975 Pontiac (LeMans, Grand LeMans, LeMans Sport Coupe, Grand Am) manual contains any recommended shift speeds, while their Plymouth and Chevrolet counterparts had begun to do so. This was the last year that Dodge and Pontiac did not recommend specific shift speeds to its vehicle owners.

By 1977, this trend to specific recommended shift speeds had expanded to the point where not only did a model type (or even series of similar models) have recommended shifting speeds, but each engine-drive train combination now had its own shift schedule. In addition to the increased number of shift schedules for each model, many manufacturers have begun to specify cruising speed ranges. Within these speed ranges, the vehicle can be driven in a cruising mode (little acceleration). These manufacturers further specify that once acceleration has ceased, the vehicle should be shifted into the highest gear allowable at that cruising speed, independent of the duration of the cruise. This is recommended even if it means skipping over a gear (i.e., shift from 2nd to 4th). Examples of owner's manuals showing these latter trends are the Ford Granada, Pontiac Astre-Sunbird, and Chevrolet Nova manuals.

The latest addition to the complexity of recommended shifting schedules appeared in 1978. Honda will be recommending (the 1978 owner's manuals are not available at this date) different shift schedules for a cold engine and a hot engine. The manual defines an engine as cold, when the water temperature gauge is reading below normal. Also, the Ford Fiesta manual contains four different schedules, all of which apply to each Fiesta sold. Different shift schedules are listed for partial throttle acceleration, wide open throttle acceleration, normal driving, and driving for fuel economy.

Shift Points Used by Other Testing Organizations

Four consumer oriented organizations which test automobiles for performance or fuel economy were contacted to discover their method for determining shift points. The four groups contacted were; Consumer's Union, Road and Track, Motor Trend, and Car and Driver magazines (7, 6, 4, 5).

Of the four groups contacted, none used the manufacturer's recommended shift points. Road and Track (6) does their fuel economy testing over a road course and all their accelerating is done at predetermined rates. Using a vehicle mounted accelerometer, their drivers accelerate their cars at a rate of 7 ft/sec^2 (0-20 mph), 5 ft/sec^2 (20-35 mph), and 3 ft/sec^2 (35-60 mph). The drivers have experience with the cars they are testing and shifting is done to keep the engine running smoothly and to hold to the above acceleration rates. No effort is made to maximize fuel economy, but rather a reasonable fuel economy, obtainable by their readers, is their goal.

The Consumer's Union (7) tests automotive vehicles for both fuel economy and performance. Their goal in fuel economy testing is to shift all vehicles as near to 15, 25, and 40 mph as possible. When it seems unreasonable to the driver to shift at these speeds, higher or lower speeds are used. From their experience, more vehicles need to be shifted at speeds higher than 15, 25 and 40 mph than need to be shifted at lower speeds. When testing for vehicle performance, the vehicles are shifted using three shift schedules. The vehicles are first shifted at the points where the engine is producing its maximum torque. Then the vehicle is shifted at speeds just higher and lower than the speeds corresponding to maximum torque. The best performance resulting from the three shift schedules is used for that vehicles performance rating.

Motor Trend (4) tests vehicles for both performance and fuel economy. When testing for performance, their drivers shift at that RPM where engine torque is at a maximum. When testing for fuel economy, their drivers shift primarily by feel. The drivers shift as early as possible while still being able to keep up with traffic and keep the engine running smoothly.

Car and Driver (5) does their city testing on a chassis dynamometer using the first 505 seconds of the LA-4 cycle. Over this cycle they still shift at 15-25-40 mph. They do their highway testing on the road and their drivers shift when it seems reasonable to them. They are currently also testing the 15-25-40 mph shift points over their highway course to determine their applicability.

Public Training in Shifting Gears

The explaination of shifting gears in driver's training manual is by necessity quite general, since every engine-vehicle-drive train combination cannot be discussed separately. Also, this aspect of driving is often dealt with quickly, since most driver's education schools use automatics. It is felt that this aspect of driving can be learned quickly by those drivers who will need to drive vehicles with standard transmissions (2, 3). Emphasis is placed on steering, braking and other skills essential to safely operating all types of vehicles.

Those manuals which do deal with manual shifting have very similar instructions (1, 2, 3, 15, 19). Most recommend shifting from first to second gear at 10-15 mph, second to third gear at 15-25 mph, and third to fourth gear (if applicable) at about 35 mph. One manual recommends looking in the owner's manual to find the exact speeds at which to shift gears (2). Another states that you can shift up one gear once you have the car moving smoothly in the present gear (19).

One driver's training instructor in Ann Arbor, Michigan said that he recommends to his classes that they shift by feel. That is, shift as soon as the engine will run smoothly in that gear. Because this and most other driver's training courses only use vehicles equipped with automatic transmissions, any instructions given by instructors or manuals are never practiced on the road. When new drivers do begin to drive vehicles with standard transmissions, they will most likely learn from a family member or friend and not from a licensed instructor or a manual. This, coupled with the difficulty of driving a car while looking at the speedometer, makes it highly unlikely that any shift speeds mentioned in training or owners' manuals make any difference in the shifting habits of the average driver. The shift speeds are most likely determined by the ability of the vehicle to accelerate at the desired rate in the present gear and the next highest gear. This can be determined by engine sound and feel and does not require the driver to take his eyes off the road.

On-the-Road Shifting Data

Actual data on the shifting of vehicles in traffic is available from four independent sources, General Motors (GM), Ford, American Motors (AMC), and the Environmental Protection Agency (EPA) (14, 18, 21). Each conducted tests to determine when vehicles were shifted during normal driving conditions. The stimulus for the studies was automobile noise, but this motive produced no known bias in the results.

The General Motors study was the most comprehensive of the four that will be presented here. It consisted of nine 1977 vehicles and one 1976 vehicle, three with automatic and seven with standard transmissions (14, 21). Only the data from the vehicles with standard transmissions will be discussed here. The vehicles were driven home for the evening and returned in the morning by GM Technical Center employees. The vehicles were also driven on business trips during the day. A total of 14,800 shifts were recorded from the seven vehicles. Each vehicle was driven by 7-13 drivers and the drivers consisted of both men and women. They ranged in age from 16 to 60 years. All of the drivers knew the vehicles were instrumented, but only some knew that it was to collect shifting data. It is the opinion of the GM staff that the data is very representative of actual driving (20).

A summary of the results of the study is shown in Table 3. In this analysis of the road data, only those accelerations where the vehicle started from a stop (or from a very low speed) and continued into high gear were used. The data was analysed in this way to facilitate its use in test procedure development with respect to vehicle noise. This type of analysis is also very useful in comparing the shifting done in actual driving to the shifting recommended by the manufacturers. Only upshifts resulting in continued acceleration are included in the analysis, except for the shift into high gear. This situation is usually described in the owner's manuals by a single recommended shift point, which is easily comparable to the results of the analysis. This situation also is a typical one in the certification driving cycles.

The mean shift points for each vehicle are shown in terms of four different quantities: absolute engine RPM, percent of rated RPM, percent of RPM at maximum torque, and vehicle speed. As could be expected from this range of vehicles, the shift points in absolute RPM and vehicle speed varied between vehicles. The results in terms of percent of RPM at maximum torque was also quite scattered. When the results were normalized in terms of percent of rated engine RPM, though, the scatter in the results for the 1-2 shift and 2-3 shift was reduced significantly. The mean shift point for the seven vehicles tested was 66% of rated RPM for the 1-2 shift with a standard deviation of 4% of rated RPM. The mean shift point for the 2-3 shift was 65% of rated RPM, while the standard deviation was 4% of rated RPM.

The normalization of the 3-4 shift data in terms of percent of rated RPM resulted in a slight increase in scatter over that of vehicle speed. This is not surprising in this case, since the shift into fourth gear would be very dependent on traffic conditions and speed limits, as well as vehicle characteristics. This raises an aspect of the 3-4 shift data

Table #3

General Motors Test Results

Vehicle (1977)	Monza (2.3L) 4-speed	Chevette (1.6L) 4-speed	Nova (4.1L) 3-speed	Camaro (4.1L) 3-speed	Camaro (5.7L) 4-speed	Chevy C-10 (5.7L) 3-speed	1976 VW Rabbit (1.6L) 4-speed
Rated RPM	4400	4800	3800	3800	3800	3800	5600
RPM at Max. Torque	2400	3200	1600	1600	2400	2400	3200
RPM 1-2 Shift	3080	3310	2430	2700	2320	2400	3640
% Rated RPM	70	69	64	71	61	63	65
% RPM at Max. Tqu.	128	104	152	169	97	100	114
N/V 1st gear RPM/MPH	159.5	208	113	113	117	109	201
Vehicle Speed	19.3	15.9	21.5	23.8	19.8	22.0	18.1
Manufacturer's Recommended Shift Spd.	10	10	20	20	15	15	15*
RPM 2-3 Shift	3210	3260	2320	2470	2356	2318	3528
% Rated RPM	73	68	61	65	62	61	63
% RPM at Max. Tqu.	134	102	145	166	98	98	110
N/V 2nd gear RPM/MPH	113	120	67	67	83	64	114
Actual shift Speed	28.4	27.2	34.6	36.9	28.4	36.2	30.9
Manufacturer's Recommended Shift Spd.	30	25	25-40	25-40	25	25-40	25*

*VW does not include specific shift points in their owner's manuals. They use the old Federal shift schedule of 15, 25, and 40 mph for certification testing.

Table #3 (continued)

General Motors Test Results

Vehicle (1977)	Monza (2.3L) 4-speed	Chevette (1.6L) 4-speed	Camaro (5.7L) 4-speed	1976 VW Rabbit (1.6L) 4-speed
Rated RPM	4400	4800	3800	5600
RPM at Max. Torque	2400	3200	2400	3200
RPM 3-4 Shift	2770	2832	1860	3250
% Rated RPM	63	59	49	58
% RPM at Max Torque	116	90	78	102
N/V 3rd Gear RPM/MPH	75.4	76.6	55.4	79.7
Actual Shift Speed	36.8	37.0	33.6	40.8
Manufacturer's Recommended Shift Speed	20-50	25-40	25-40	40*

*VW does not include specific shift points in their owner's manuals. They use the old Federal shift schedule of 15, 25, and 40 mph for certification testing.

and of the 2-3 shift data for the three speed vehicles. An unknown number of these shifts were the result of the driver reaching the desired vehicle speed and were not due to the normal limit of acceleration in that gear being reached. This will have to be taken into account when comparing this data to the shift speeds recommended by the manufacturers.

Ford tested a single 1976 Pinto over a city-suburban route to determine the point at which the transmission was shifted between 1st and 2nd gears (14, 18). Four drivers were used in the study. The RPM at the 1-2 shift was recorded off a tachometer by an observer in the vehicle. The drivers could not read the tachometer, but did know the purpose of the tests. The results are shown in the first column of Table 4. The four driver average was 79% of the rated RPM.

The EPA study was conducted on the Marana Air Park grounds in Marana, Arizona, by Wyles Laboratory (14). Eight vehicles were tested, but only the three vehicles having standard transmissions are discussed here. The drivers were employees of Evergreen Airlines, both men and women, young and old. The vehicles were driven over a course consisting of a loop with six stop signs. The drivers were told individually that 20 different drivers in three vehicles were being used to determine how people normally drive. If questions arose, it was explained that engine RPM and acceleration were being monitored to determine when people normally shift gears. The drivers were instructed to drive normally and were given one time around the loop to become acquainted with the course before data was taken. The test under these conditions consisted of five loops around the track or 30 sets of shifting through the gears per driver. The results of the study are shown in Table 4. Again there is good consistency for the 1-2 shift point in percent of rated RPM. In this study, where the engines of the three vehicles were of very similar size, the shift points in absolute RPM vary even less than in percent of rated RPM.

The AMC study consisted of two vehicles, a 1977 Pacer and a 1977 Gremlin, instrumented to record the engine speed at the shift from 1st to 2nd gear (14). The drivers consisted of AMC personnel, who drove the vehicles home overnight and returned them in the morning. The drivers were not told that the vehicles were instrumented and the use of the vehicles during the evening was not restricted. The two drivers, though, did not normally drive cars with standard transmissions, but owned cars with automatics. The results of this study are also shown in Table 4. Again, the mean shift points of these two vehicles in percent of rated RPM lie within the range of values set by the previously mentioned studies. The Pacer shifted at 67% of rated RPM and the Gremlin at 63% of rated RPM. The fact that the drivers were not used to driving with a standard transmission did not seem to affect the results significantly.

Examination of all the data in Tables 3 and 4 shows that the 1-2 shift points of the vehicles vary significantly in absolute RPM (2320-3940 RPM), percent of RPM at maximum torque (87%-169%), and vehicle speed (15.7-23.8 mph). When the 1-2 shift points are normalized into

Table #4

Ford, AMC, and EPA Test Results

Tester:	Ford	EPA (1977's)			AMC (1977)	
Vehicle:	1976 Pinto 2.3L 4-speed	VW Rabbit 1.6L 4-speed	Corolla 1.6L 4-speed	Chevette 1.4L 4-speed	Pacer 258CID 4-speed	Gremlin 121 CID 4-speed
Rated RPM	5000	5500	5800	5200	3600	5000
RPM at Max. Torque	3000	3200	3800	3600	2000	2300
1-2 Shift RPM	3940	3460	3310	3330	2410	3170
% Rated RPM	79.0	63	57	64	67	63
% RPM at Max. Torque	131	108	87	92	120	138
N/V 1st gear RPM/MPH	169.3	201	210	208	128	168
Actual Speed	23.3	17.3	15.7	16	18.7	18.8
Manufacturer's Recommended Shift Speed	10	15*	12	10	10-15	10-15

*VW does not include specific shift points in their owner's manuals. They use the old Federal shift schedule of 15, 25, and 40 mph for certification testing.

percent of rated RPM, the range is narrowed to only 57%-79%. Statistically, the mean shift point of all 13 vehicles is 66% of rated RPM, and the standard deviation is 5% of rated RPM. It is interesting to note that many of the unusual factors involved in some of the studies had little effect on the results. The EPA study was performed on a track, where traffic conditions were not typical. Yet the VW Rabbit was shifted only 2% of rated RPM earlier than the Rabbit in the GM study, while the Chevette was shifted 5% of the rated RPM earlier than in the GM study. The AMC drivers, who were not used to driving with a standard transmission, shifted the two vehicles at an average of 65% of rated RPM, which is nearly at the overall mean of 66%. The Ford study, where a passenger rode in the car to record shift speeds, resulted in the largest deviation from the mean, 13% of rated RPM. It would appear from the EPA and AMC results that it might not be essential to have perfectly representative traffic patterns or drivers to arrive at reasonable results.

Also shown in Tables 3 and 4, just below the vehicle speed at shifting, is the manufacturer's recommended shift speed for that vehicle-engine-drive train combination (from the owner's manual). A comparison can be made between the speed the vehicle is shifted on-the-road, and the shift speed recommended by the manufacturer. Of the 11 vehicles where this comparison can be made, for the 1-2 shift, in all cases the manufacturer's recommended speed was less than the actual speed at shifting. The largest differences occurred for those sub-compacts whose recommended shift speeds were 10 mph. None of these vehicles were shifted below 15 mph. The two AMC vehicles, which have suggested shift speeds of 10-15 mph were both shifted at over 18 mph. The only vehicles which were shifted at speeds within 20% of the recommended shift speed were the two vehicles whose recommended shift speeds were 20 mph (Nova and Camaro (16)).

No recommended shift speeds are shown in the owner's manual for the VW Rabbit, though a range of possible operating speeds is given for each gear. The Rabbit is shifted at the previously standard 15-25-40 mph shift points when tested by the EPA so these speeds have been listed in Tables #3 and #4. If this 15 mph shift point was compared to the actual shift points (17.3 and 18.1 mph), again the actual shift speeds are greater than those used in certification testing by the EPA.

Similar comparisons of the 2-3 and 3-4 shift data shown in Table #3 can also be made. The 2-3 shift point data for the 4-speed vehicles includes only those accelerations which continued in third gear. The 2-3 shift data for the three speeds and the 3-4 shift data includes those accelerations which continued after the shift and also those which did not continue. To reflect this difference, the recommended shift speed or range of speeds in the owner's manuals pertinent to the type of shift occurring have been listed in Table 3.

The 2-3 shift data, like the 1-2 shift data shows a nearly constant shift point in terms of percent of rated RPM. The mean is 65% of rated RPM and the standard deviation is 4% of rated RPM. The 3-4 shift data shows a fairly constant shift point around 57% of rated RPM, with a

standard deviation of 6% of rated RPM. The scatter here is greater than in the 1-2 and 2-3 shift point data, due most likely to shifting occurring when cruise speed has been reached. Since shifting when the desired cruise speed has been reached lowers the shift point, when compared with the situation where acceleration is continued in fourth gear, the results for the 3-4 shift in Table #3 set a lower limit on 3-4 shifting when continued acceleration is desired. Exactly how much higher the actual shifting speed for continued acceleration is cannot be determined without further analysis of the GM data.

A comparison of the vehicle speeds at which the 2-3 shift occurs with the manufacturer's recommended speed shows that the two speeds are nearer each other than for the 1-2 shift. The four vehicles with recommended shift speeds of 25 mph were still all shifted later though. The greatest difference was found with the VW Rabbit which was shifted at 30.9 mph. The Monza was actually shifted sooner than recommended; 28.4 mph vs. a recommended 30 mph. The three three-speeds were shifted at or near the upper limits of the range of shift speeds recommended for that gear. This would indicate that at least the upper 5-10 mph of the recommended range of shift speeds is reasonable and representative for these three vehicles.

A comparison of the vehicle speeds at the 3-4 shift yields results similar to the results of the 2-3 shift for the three-speeds. The VW was shifted right at its certification 40 mph shift speed. The 36.8 mph shift point for the Monza demonstrates that the 35-50 mph section of the recommended shifting range is representative. Similarly, at least the 35-40 mph section of the Chevette range and the 30-40 mph section of the Camaro, are representative of actual driving.

To be able to show that the low ranges of the recommended 2-3 shift speeds (3-speeds) and 3-4 shift speeds (4-speeds) are representative or not, a significant portion of the data gathered by GM has been re-analyzed by EPA personnel to examine the cruise speeds at which people begin to up-shift their vehicles. In this re-analysis, when a vehicle entered a cruise after an acceleration, the cruise speed and whether or not the driver shifted were recorded. A cruise was defined as a period of time at least three seconds long where all accelerations and decelerations were of an absolute magnitude of approximately 0.5 mph per second or less. An acceleration (deceleration) was defined as any period of time where speed was increasing (decreasing)(and any time of constant speed after it) which was not a part of any cruise. In this way, the entire range of speeds which the manufacturers recommend for shifting into a cruise could be evaluated.

The results of the analysis are shown in Table #5. The percentage of the time the vehicle was shifted into a higher gear upon entering a cruise from an acceleration is shown for various ranges of cruise speeds. For example, when the Nova began a cruise between 22.5 and 27.5 mph, the various drivers only shifted into third gear 36% of the time. At cruises between 27.5 and 32.5 mph, the drivers shifted 74% of the time. The vehicle cruising speed at which the vehicle was shifted into a higher

Table #5

Analysis of Shifting into Cruise from an Acceleration
General Motors Data

Vehicle (1977)	Monza	Chevette	Nova	Camaro (L-6)	Camaro (V-8)	C-10* Pick-up	1976 Rabbit
Cruise Speed (mph)	Percent of Time Vehicle was In or Shifted Into 3rd Gear Upon Entering a Cruise						
12.5-17.5	20	14			0		0
17.5-22.5	44	62	8	10	71		25
22.5-27.5	54	96	36	45	79	0	60
27.5-32.5	89	98	74	92	91	50	100
32.5-37.5			95	93	100	56	
	Cruise Speed where Shifting Occurred 50% of the Time - mph (% Rated RPM)						
	23 (59)	19 (48)	27 (48)	26 (46)	19 (42)	30 (51)	24 (49)
	Minimum of Manuf. Recom. Range of Shift Speeds - mph						
	15	-	25	25	-	25	19
Cruise Speed (mph)	Percent of Time Vehicle was Shifted Into 4th Gear Upon Entering a Cruise						
22.5-27.5	8	20			43		0
27.5-32.5	47	37			45		35
32.5-37.5	60	79			73		77
37.5-42.5	85	90			75		90
	Cruise Speed Where Shifting Occurred 50% of the Time - mph (% Rated RPM)						
	31 (53)	32 (51)			31 (45)		32 (46)
	Minimum of Manuf. Recom. Range of Shift Speeds - mph						
	20	25			25		25

* Only a very limited amount of data was available for re-analysis.

gear approximately 50% of the time (50% shift speed) has been estimated by linear interpolation and is also shown in Table #5. The engine speed in % of rated RPM is also shown for each of these vehicle speeds. An examination of the 50% shift speeds for all the vehicles again shows very low variability in terms of % of rated RPM. In fact, there appears to be no difference between the 2-3 shift and the 3-4 shift. The means of both sets of data are 49% of rated RPM. This is not surprising since the 2-3 shift of the 3 speeds and the 3-4 shifts of the 4 speeds are both shifts into high gear. Also, the ability of the vehicle to hold a constant speed should occur at approximately the same engine speed for a given vehicle, regardless of the gear it is in. Thus, with all the data in Table #5 analyzed together, the average 50% shift speed is 49% of rated RPM and the standard deviation is 5% of rated RPM. The C-10 pick-up was excluded from this final analysis because only a very small portion of its data was available for re-analysis.

The cruise speeds where up-shifting occurred 50% of the time can also be compared to the lower limit of the ranges of shifting speeds recommended by the manufacturer when the vehicle is entering a cruise. The lower limits are listed in Table #5. In all nine cases in Table #5 where comparisons can be made, the 50% shift speed is greater than the lower limit of the manufacturer's recommended range of shift speeds, which is used during certification. The differences range from 4% for the 2-3 shift of the 6 cylinder Camaro to 55% for the 3-4 shift of the Monza. The average difference of the nine cases is 27%. The owner's manuals of the Chevette and Camaro (V-8) do not recommend a range of shift speeds for entering a cruise for the 2-3 shift. The 2-3 shift into a cruise for these two vehicles was still analyzed to allow the number of vehicles to be as large as possible for determining the engine speed at which shifting occurs upon entering a cruise.

At the same time the GM data was being re-analyzed for shifting into a cruise from an acceleration, two other aspects of shifting which are relevant to driving over the Federal certification driving cycle were analyzed. First, the data were examined to determine if the vehicles were being double-shifted as is recommended under certain conditions in the owner's manuals. After examining thousands of shifts, only two double shifts were found. Both occurred with the V-8 Camaro and were 1-3 shifts at 22-25 mph. Shifts from first to third gear at this speed are not recommended by the manufacturer. Where numerous occasions arose where the manufacturers did recommend double shifting, not a single one occurred.

Secondly, the situation of a vehicle entering a deceleration after an acceleration was examined. The deceleration had to be at least 3 seconds long and had to begin within 3 seconds of the end of the acceleration (i.e., no cruising occurring between the acceleration and deceleration). This situation occurs a number of times during the certification driving cycle and the shifting done at the transition appears to assume that the 1 or 2 seconds spent at the peak speed is a cruise. It was to verify this assumption that this particular analysis was performed.

Table #6

Analysis of Shifting into a Deceleration from an Acceleration
General Motors Data

Vehicle (1977)	Monza	Chevette	Nova	Camaro (L-6)	Camaro (V-8)	C-10* Pick-up	1976 Rabbit
Peak Speed (mph)	Percent of Time Vehicle was in or Shifted into 3rd Gear Upon Entering a Deceleration						
12.5-17.5	9	17		-	-		0
17.5-22.5	63	23	0	8	0	-	0
22.5-27.5	74	47	9	16	20	-	25
27.5-32.5	82	88	24	48	67	-	100
32.5-37.5			64	27	73	-	-
	Peak Speed where Shifting Occurred 50% of the Time (mph)						
	19	25	33	>30	28		27
Peak Speed (mph)	Percent of Time Vehicle was Shifted Into 4th Gear Upon Entering A Deceleration						
22.5-27.5	6	0			0		0
27.5-32.5	12	17			22		16
32.5-37.5	64	10			27		25
37.5-42.5	100	63			-		84
	Peak Speed where Shifting Occurred 50% of the Time (mph)						
	34	39			>35		37

* Insufficient amount of data available to analyze.

The results of this analysis appear in Table #6, arranged similarly to the results shown in Table #5. In all cases except for the 2-3 shift of the Monza, shifting into a deceleration occurs only at significantly higher speeds than shifting into a cruise. For example, while the Nova was being shifted 74% of the time upon entering a 30 mph cruise, the same Nova was being shifted only 24% of the time upon entering a deceleration at the same speed. For the 2-3 shift of the Monza, the situation was reversed. It should be noted, though, that the 50% shift into cruise occurred at a higher engine speed for the 2-3 shift of the Monza than for any other vehicle, so if the shift into cruise and shift into deceleration could be expected to be similar for any vehicle, it would be for this shift of the Monza.

Discussion

The EPA tests vehicles for both gaseous emissions and fuel economy. The results obtained from these tests are intended to be representative of the emissions and fuel economies of production vehicles as they are driven on the road. Much time and effort has been put into the development of representative driving cycles and dynamometers which convey actual driving conditions to the vehicles. Care is taken to insure that the certification vehicles are representative of the production vehicles that will follow. In the same way, the shifting patterns used over the Federal Test Procedure should be representative of those used on the road by average drivers.

Currently, the shifting patterns used during vehicle certification are those recommended by the auto manufacturers in their owner's manuals (11). Originally this was not the case. The shifting pattern in terms of vehicle speeds was set by law. In the 1972 model year this was changed to allow the auto manufacturers flexibility to set different shifting patterns for their vehicles, since considerable differences occur between vehicles. It was assumed that any changes made would still be representative of the way those particular vehicles were driven on the road. If the recommended shift patterns found in owner's manuals were actually used by the majority of drivers, this assumption may have proven correct. At present, though, little data can be brought forth to show that drivers shift as recommended by their owner's manuals. Thus, the auto manufacturers can, if they desire, recommend any of a wide range of shift patterns, with no adverse effects to their customers satisfaction due to poor vehicle performance.

How do people decide when to shift? The evidence available from driver's education teachers and manuals suggests people do not learn when to shift during driver's education. The great majority of automobiles used to train drivers have automatic transmissions. To suggest that drivers watch their speedometers and temperature gauges and shift at a certain speed listed in their owner's manual is just as unlikely. A driver is most likely going to shift in such a way that the engine will operate smoothly and that the vehicle will accelerate at the desired rate. If anyone recommends shifting into second gear at 10 mph and the vehicle lugs at the desired acceleration rate, the driver is going to shift later next time.

This is confirmed by four consumer oriented groups who test automobiles, the Consumer's Union, Road and Track, Motor Trend, and Car and Driver magazines. None use the recommended shift schedules given in the owner's manuals in their testing. All four allow their drivers flexibility in determining when to shift, except for the urban fuel economy testing done by Car and Driver, who use the old Federal standard 15-25-40 mph shift schedule. The drivers keep the engine running smoothly and do not attempt to obtain the optimum fuel economy, but aim for a fuel economy their readers can obtain with their own cars.

The idea that people do not shift as their owner's manuals recommend is even more strongly confirmed by data gathered by the auto manufacturers themselves and the EPA. Summarized in Tables #3 and #4, the results of these four studies show that on the average, people shift into second gear at a speed 44% greater than that recommended by the manufacturer. (A recommended speed of 15 mph was used for the VW Rabbit, since this is what VW recommends for use during certification.) The data ranged between 8% greater for the Nova and 133% greater for the Pinto.

The results for the 2-3 and 3-4 shifts (Table #3) show that the actual and recommended shift speeds are much closer to each other than for the 1-2 shift. The three 4-speed vehicles with a recommended 2-3 shift speed of 25 mph were all shifted at higher speeds. The differences ranged from 2.2 mph (Chevette) to 5.9 mph (Rabbit). The 4-speed Monza, with a recommended shift speed of 30 mph, was shifted earlier at 28.4 mph. Except for the VW Rabbit, these differences are small.

The 2-3 shift results for the three 3-speed vehicles are also more difficult to interpret, though, because of the possibility of shifting upon reaching cruise speed. The results show that at least the section between 30 mph (Nova) or 35 mph (Camaro and C-10 pickup) and 40 mph are representative of normal driving. Similarly, the 3-4 shift results (Table #3) show that the upper section of the recommended shift speed ranges are representative of normal driving (GM vehicles) for the 4-speed vehicles. The VW certification shift speed of 40 mph appears very representative.

To evaluate the representativeness of the lower end of the speed ranges recommended by the manufacturers for shifting into a cruise, the results of the re-analysis of the GM data can be used (Table #5). As can be seen from the results in both tables, none of the vehicles is being shifted most of the time at the lower limit of the shift speed range recommended by the manufacturers. Overall, the speed where the vehicles are shifted half the time is 27% greater than the lower limit recommended by the manufacturers. Thus, it appears that in this area, also, people shift later than the manufacturers recommend and, thus, later than shifting is done during certification.

There are also sections of the certification driving cycle where an acceleration is followed very closely by a deceleration. Under these circumstances, the vehicle is often shifted as if it has entered a cruise after the acceleration. It was felt that this might not be the case in actual driving, so the General Motors data was re-analysed to determine the representativeness of shifting into a deceleration as if it were a cruise.

The results showed that for nine out of ten of the comparable cases (Tables #5 and #6, 6 vehicles for 2-3 and 3-4 shifts), the shift into decelerations occurred only at significantly higher speeds than did the shift into cruises. For the 3-4 shift of the Chevette and the Camaro (V-8), the peak speed where shifting occurred 50% of the time was even

greater than the average shift speeds listed in Table #3. Thus, it appears that shifting into a deceleration from an acceleration does not occur at the same speeds as shifting into a cruise, but occurs at a speed much closer to the average shifting points (shown in Tables #3 and #4).

The last aspect of the shifting of cars pertinent to this study is double shifting. Manufacturers have begun to recommend double shifting when entering a cruise if the cruise speed is high enough. For example, it would be the manufacturer's recommendation to double shift the Chevette, Camaro (V-8) and Monza from 2nd to 4th gear upon entering a cruise at a speed of 25 mph. This particular driving situation should occur very frequently on the road and a re-analysis of the General Motors data verified that many 25 mph cruises are entered from 2nd gear. While many drivers shifted into 3rd in this situation, not one double shifted into 4th gear. During the re-analysis of the GM data, only two double shifts were found and both were from first to third gear at about 22-25 mph, which is not recommended by the manufacturer. This result would seem to state that drivers do not double shift these types of vehicles on the road and to be representative, double shifting should not occur over the certification driving cycles.

The question which arises next is: Does it make any difference when the cars are shifted? The evidence available strongly indicates that the shifting pattern used over the certification cycle affects both emissions and fuel economy significantly. A study performed by Peter Hutchins of the EPA reports on tests of three vehicles over the current Federal Test Procedure with different shifting patterns (12, 13). The results are shown in Table #7.

As can be seen, by shifting earlier fuel economy is significantly increased while carbon monoxide emissions are decreased. The Toyota showed an 11.7% fuel economy increase and a 4% carbon monoxide decrease from the use of shift schedule #1 as compared to #4. The VW showed a 11.5% fuel economy increase and a 7% carbon monoxide decrease from the use of schedule #4 as compared to #5. The Chevette showed a 10.8% increase in fuel economy and a 30.4% decrease in carbon monoxide emission due simply to the small differences between schedules #2 and #4. The effect of shift schedules on hydrocarbon and nitrogen oxide emissions appears to be vheicle specific. Thus, the shifting schedule used during certification has an effect on emission and fuel economy. If the shifting schedule is not representative of typical shifting then neither will the emissions or fuel economy be representative.

It is then necessary to insure that the shifting schedules used during the certification process are representative of those used on the road. This can be done most effectively in one of four ways. First, the EPA could determine typical shifting patterns for various automobiles when driven on the road and derive a correlation for shifting speeds based on vehicle parameters. A quick look at Tables #3 and #4 shows that the shift speed in % of Rated RPM for all the vehicles varies

Table #7

Shift Sequence	HC	CO	CO_2	NOx	Urban Fuel Econ. (MPG)
		(Grams per mile)			
Toyota TTC-1 Lean Burn					
1*	1.14	6.43	295	1.55	28.7
3**	1.06	6.73	314	1.60	27.1
4**	1.06	6.69	332	1.51	25.7
VW Turbocharged Diesel					
4*	0.42	0.93	226	1.01	44.5
5**	0.50	1.00	252	1.24	39.9
1977 Chev. Chevette					
2*	0.21	2.75	294	1.52	29.7
4**	0.30	3.95	325	1.36	26.8
6**	0.35	4.85	345	1.30	25.1

Shift Sequences	Shift Points (MPH)			
	1-2	2-3	3-4	4-5
1	10	20	26	45
2	10	25	25-40***	
3	12	22	30	
4	15	25	40	
5	18	30	47	
6	Shift using Peak Torque Bracketing			

* Manufacturer's Recommended Shift Schedules.

** Shift Schedules more representative of in-use driving.

*** Shift at highest speed shown unless cruise speed has been reached.

only slightly and could be the basis for such a correlation. Or it might turn out that after other parameters, such as vehicle weight, horsepower, etc., are included, a better correlation would result using absolute RPM. In either case, considerable time and effort would most likely be needed to come up with such a correlation, which would be similar to the one currently used for road load dynamometer settings. To insure a reasonable amount of flexibility and accuracy, changes could be allowed if the manufacturer could show that on the road data supported them, again similar to the method for determining road load settings.

A second way to insure more representable shifting patterns would be a simpler version of the first method. That would be to return to the original 15-25-40 shifting pattern and then require the manufacturers to demonstrate using test data why a different shifting pattern would be more representative. This would require less time and effort than the first method, but would put a large amount of work on the manufacturers if they desired to change the shifting patterns of a considerable number of cars. Both this method and the first would require a change in the regulations governing emission and fuel economy test procedures.

A third method which could be implemented sooner and one which shouldn't require a change in the statutes would be to require manufacturer's to demonstrate that their recommended shifting patterns are representative. The need for representativeness is implicit in the entire automotive pollution control and fuel economy program. Under this method, any questionable patterns could be returned to the manufacturer asking for data supporting these patterns. Again, this method would require little time and effort to implement.

The final method would simply be to allow the drivers to shift when they think it is reasonable, always staying as close to the driving trace as possible. This raises problems of increased variability due to differences between drivers and also the need to change the regulations. It does not require any lead time, though, as does the first method and could be implemented as soon as the regulations could be changed.

Recommendations

The recommendation of this report is that the above third method be implemented as soon as possible. The following guidelines appear to be most useful to assure that vehicles are shifted in a manner representative of in-use operation:

1) The 1-2 shift point should be at 66% of rated engine RPM, possibly allowing up to 5% of rated engine RPM deviation;

2) The 2-3 shift point should be at 65% of rated engine RPM, possibly allowing up to a 4% of rated engine RPM deviation;

3) The 3-4 shift point should be at 57% of rated engine RPM, possibly allowing up to 6% of rated engine RPM deviation;

4) The minimum speed at which a vehicle is allowed to upshift into a cruise should be 49% of rated engine RPM, possibly allowing up to a 5% of rated RPM deviation;

5) A cruise in the Federal certification driving cycle should be defined as a period of time at least three seconds long during which all accelerations and decelerations (measured over one second intervals) are of an absolute magnitude of 0.5 per second or less;

6) The minimum speed at which a vehicle is allowed to be upshifted into a deceleration from an acceleration (no cruise as defined in #5 in between) should be the same speed as for upshifting into an acceleration, which is stated in Guidelines #1, #2, and #3.

7) No double up-shifting of vehicles with 3 or 4 speed transmissions should be allowed;

8) If a manufacturer's recommendation does not meet the previous guidelines, he should be allowed the opportunity to submit data supporting the deviations. If no convincing data are presented, the above guidelines should be used for shifting that vehicle during certification testing.

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